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POSSIBILITY OF APPLICATION OF THZ WIGGLER IN LOW ENERGY FEL FOR MEASUREMENTS OF ELECTRON BUNCH LONGITUDINAL STRUCTURE

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Abstract

The infrared undulator constructed at JINR and installed at FLASH in 2007 is used for longitudinal bunch shape measurements in the range of several tenths of µm.

The presented below electromagnetic wiggler is applied for a narrow-band THz radiation for measurements of electron bunch longitudinal structure in FEL with electron energy of several tenths of MeV. This is a planar electromagnetic device with 6 regular periods, each of 30 cm long. The K parameter is varied in the range 0.5-7.12 corresponding to a range B=0.025-0.356 T of the peak field on axis. The wiggler is simulated for 19.8 MeV/c FEL. The bunch compression scheme allows the whole wavelength range to be covered by super-radiant emission with a sufficient form factor. The wavelength range corresponds to 126 µm - 5.1 mm for the electron beam momentum of 19.8 MeV/c. The 3D Opera simulations of THz wiggler will be discussed.

JINR FAR INFRARED UNDULATOR AT FLASH

The FLASH was equipped with an infrared electromagnetic undulator, tunable over a K–parameter range from 11 to 44, and producing radiation up to 200 µm at 500 MeV and up to 50 µm at 1 GeV [1-5]. The undulator is used for longitudinal electron bunch measurements. It was designed and constructed at JINR according to the FLASH requirements. The undulator period corresponds to 40 cm, the number of periods is 9, the magnetic field is varied in range of 0.1-1.1 T. Output undulator radiation has following parameters: the wavelength in the range of 5-200 µm, the peak power of ~4MW, the micropulse energy of 1 mJ and the micropulse duration of 0.5-6 ps.

The energy radiated by the FIR undulator is defined by the number of electrons per bunch N and a form-factor of an electron bunch F(λ):

$$\varepsilon_{coh} = \varepsilon_e \times \left[N + N(N-1)\left|\bar{F}(\lambda)\right|^2 \right],$$

where ε_e is energy radiated by a single electron. The form-factor is determined by the temporal profile of the electron beam and e.g. for Gaussian bunches with r.m.s. length σ it yields $|F(\lambda)|^2 = \exp(-2\pi\sigma/\lambda)^2$. When the wavelength is longer than the bunch length, the coherent radiation dominates. In this case measuring the spectrum can yield the form-factor and thus the charge distribution and the bunch leading spike length. The Gaussian fit (Fig.1) corresponds to the r.m.s. leading spike length of σ_{ls}= 12 µm. The r.m.s duration of FIR pulse radiation is equal to $\tau_{FIR}=\sigma_{ls}/c$=40 fs.

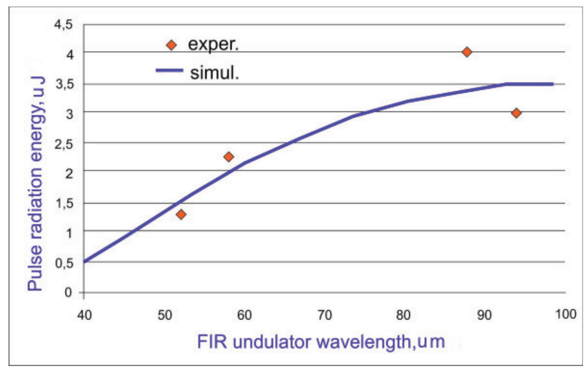

Figure 1: Dependence of the FIR undulator pulse radiation energy on the wavelength.

3D ELLIPSOIDAL ELECTRON BUNCH

The new photo cathode laser system [6-8] is proposed for the high brightness electron beam. The main goal is a production of 3D ellipsoidal electron bunches with a charge density close to the homogeneous. This corresponds to the almost linear space charge forces within the bunch and, therefore, to the minimization of the space charge contribution to the overall beam emittance budget.

Beam dynamics simulations have demonstrated a significant reduction of the transverse emittance of electron bunched produced by applying 3D ellipsoidal laser pulses to the rf photo gun [9]. Such a system capable to produce 3D quasi ellipsoidal pulses is under development at the IAP RAS, Nizhny Novgorod, Russia. The Photo Injector Test facility at DESY, Zeuthen site (PITZ) develops high brightness electron sources for modern Free Electron Lasers (FELs), like FLASH and the European XFEL. The photocathode laser system is one of the key issues for the photo injector optimization. Currently, the PITZ photo cathode laser is feasible to generate cylindrical pulses with flattop temporal profiles. Tests of the new photocathode laser system with 3D shaped pulses are considered as a next step in the high

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brightness electron source optimization. The laser system developed at IAP RAS is intended to be installed at the PITZ accelerator for experimental tests with electron beam production. The electron bunches with mean momentum of up to 19.8 MeV/c and the r.m.s. pulse duration of ~7.2 ps are expected in the PITZ accelerator with a new laser system. The installation of magnetic chicane in PITZ permits to reduce the r.m.s. electron bunch duration towards ~0.66 ps, which corresponds to the bunch length of 200 μm. Below we assume that the electron bunches will compressed in a PITZ magnetic chicane.

The infrared wiggler [10] is proposed for measurements of longitudinal shape of the 3D ellipsoidal electron bunch. As it was done at FLASH we plan to estimate the form factor of a 3D ellipsoidal electron bunch on base of the radiation energy measurements. For small angles, typical for radiation of PITZ relativistic electrons, transverse effects are strongly suppressed. For the 3D ellipsoidal bunch shape $(x^2+y^2)/5\sigma_x^2+(ct)^2/5\sigma_z^2\leq 1$ $S(x,y,t)=1/(4\pi\times 5^{3/2}\sigma_x^2\sigma_z^2)$ the form factor is defined by the relation $F(\omega)=\int dxdy\int S(x,y,t)\exp(i\omega t)dt$. After integration one obtains $F(\varphi)=3/(5\varphi^2)\times\{\sin(5^{1/2}\varphi)/(5^{1/2}\varphi)-\cos(5^{1/2}\varphi)\}$, where $\varphi=\omega\sigma_z/c$. As it was mentioned above the form factor of the Gaussian beam is $F(\varphi)=\exp(-\varphi^2/2)$. The dependences of the squared form factor $F(\varphi)^2$ on φ are shown in Fig. 2 compared to the Gaussian and flattop cases. Whereas the dependencies for the flattop and 3D ellipsoidal bunches show qualitatively similar behavior, they differ significantly from the Gaussian case.

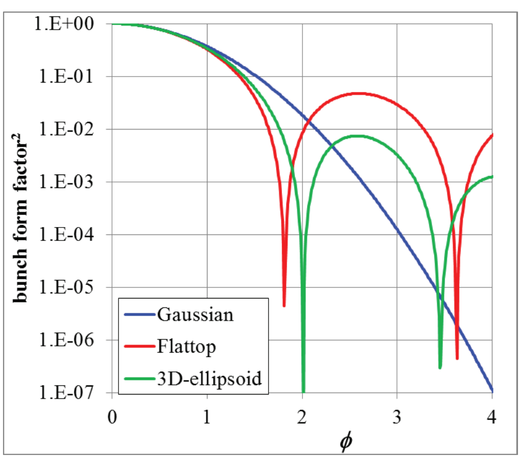

Figure 2: Dependence of the squared form factor for the Gaussian (blue), flattop (red) and ellipsoidal (green) beams on $\varphi=\omega\sigma_z/c$.

First experimental tests with new photocathode laser system [6,7] have shown that generated laser pulses deviates from the ideal 3D ellipsoidal shape. A finite border sharpness is one of such imperfections. In order to investigate the influence of the finite border sharpness onto the electron beam emittance corresponding modelling for beam dynamics simulations have been performed [9]. Evaluations for the border thickness of 10% yiled ~10% emittance growth [9].

The bunch border imperfection [6-8] is approximated by $(x^2+y^2)/5\sigma_x^2+(ct)^2/5\sigma_z^2\leq 1+\delta\times\sin(2\pi mct/5^{1/2}\sigma_z)$, where $\delta\cong 0.1$ is amplitude of the border oscillations, m=2 or m=3 is number of harmonic. The imperfection of the bunch border became to modification of the form factor at high frequencies (Fig. 3).

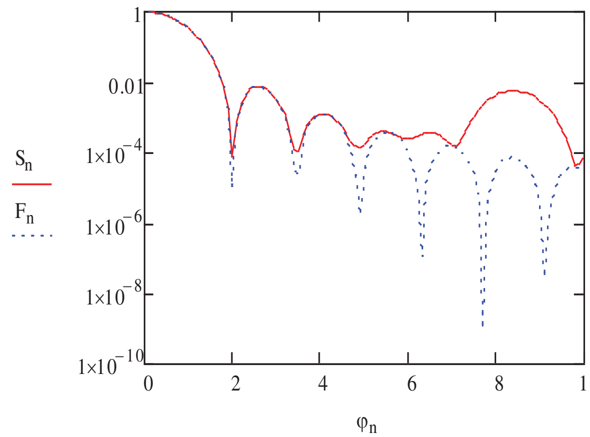

Figure 3: Dependence of the squared form factor of ellipsoidal bunch with ideal 3D ellipsoidal shape (dashed line) and with border imperfection (solid line at δ=0.1 and m=3) on $\varphi=\omega\sigma_z/c$.

One can define square of form factor and longitudinal length of 3D elliptic bunch at the energy radiation measurements with different wave lengths [3-5]. To obtain the bunch length and extract the imperfection of the ellipsoidal bunch shape the phase range should be about $10>\varphi>0.32$, where $F(0.32)^2=0.9$. This phase range corresponds to the wavelengths of 124μm<λ<3.9 mm for the bunch length of σ_z=200 μm after the compression.

THZ WIGGLER APPLIED FOR BUNCH SHAPE MEASHUREMENTS

The design of THz wiggler [10] (Fig. 4 and Table.1) and technical solution at its construction are based on the FIR FLASH undulator constructed at JINR [1-5].

In accordance with 3D TOSCA simulations of the magnetic field (Fig.5) its transverse component is smaller than -0.1% at the aperture of 20 mm (Fig.6).

The first wiggler peculiarity is related to a large clear gap between its main coils. Diffraction spot size of radiation defines the diameter of the vacuum chamber and wiggler gap. The diffraction angle and spot radius of wiggler radiation are equal to $\theta_d\cong(\lambda/2L)^{0.5}$ and $r_d\cong(\lambda L/2)^{0.5}/\pi$ correspondingly, where L=2.1m is the wiggler length and λ is the wavelength. The diffraction parameters θ_d/r_d are equal to 30.5mrad/2.2cm at the wavelength of 4.3 mm.

Same input in the transverse size at the wiggler exit gives angle spread of photon radiation $r=L\theta/6$, where $\theta=K_{rms}/\gamma N^{1/2}$, γ is the relativistic factor, N is the number of

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wiggler periods. This size is equal to 1.2 cm at the maximum field.

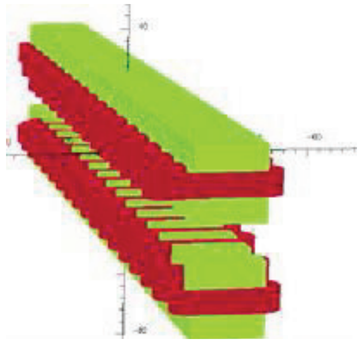

Figure 4: TOSCA 3D simulation of THz wiggler.

Table 1: Summary of Wiggler Technical Data

Parameter of THz wiggler	value
period length, mm	300
number of full periods	7
number of poles including end-pieces	14+4
maximum wiggler parameter, K_{rms}	7.12
peak field on axis, T	0.356
minimum field on axis, T	0.025
electron momentum, MeV/c	19.8
maximum wave length, mm	5.1
minimum wave length, mm	0.12
clear gap, mm	100
position accuracy of magnetic axis, mm	0.5
angular precision of magnetic axis, mrad	0.5
field flatness at ±20 mm off-axis (horizontally), %	-0.1… +0.5
first field integral I1, G×cm	50
second field integral I2, G×cm^2	500
stability and reproducibility of magnetic axis, mm/μrad	±0.1/ ±50

The second peculiarity of the wiggler is related to the trim coils. The four trim coils with individual power supply should be installed in the wiggler. These trim coils permit to compensate on the full wiggler length the first and the second integrals. However it does not permit to compensate the integral on the period length. The first integral over the period length should be smaller than 50 G×cm and also the second integral should be as low as 500 G×cm^2. To provide both these requirements it is proposed to install an additional correction coil in each regular coil.

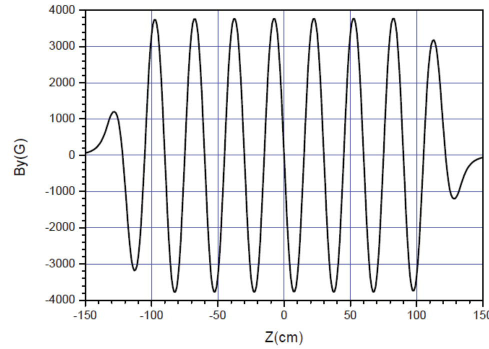

Figure 5: Dependence of wiggler magnetic field on longitudinal coordinate.

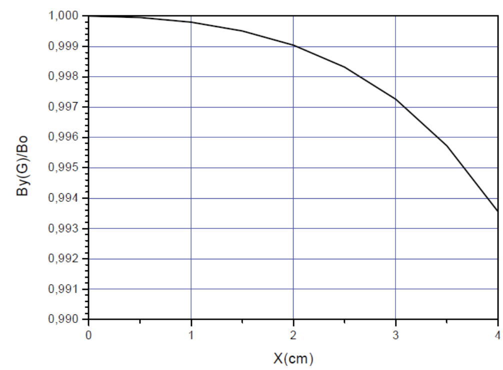

Figure 6: Dependence of the normalized wiggler magnetic field at Iw=21.5 kA×turns on transverse coordinate.

ACNOWLEGMENTS

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